# Characterization technique:
# Scanning electron microscope(SEM)

**Outlines:**

1. Introduction of characterization technique
2. Structure and different components of SEM
3. Working of SEM
4. Applications

# Prerequisite/Recapitulations

Knowledge of basics of quantum mechanics

# Objectives

After the completion of this lecture, you will be able to:

1. Understand the structures of SEM
2. Working of SEM
3. Applications of SEM

# Introduction

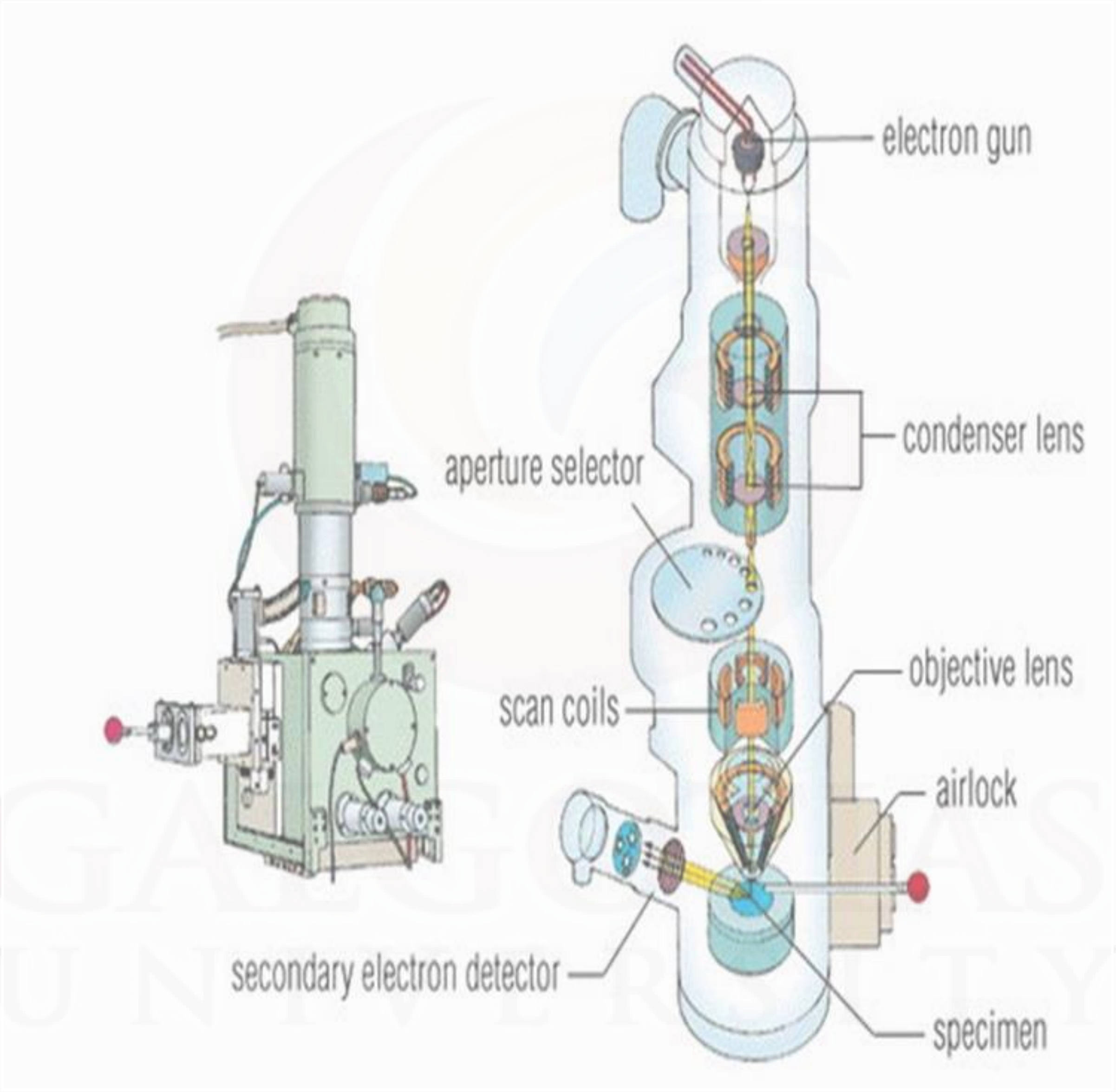
Electron Microscopes were developed due to the limitations of Light Microscopes which are limited by the physics of light to 500x or 1000x magnification and a resolution of 0.2 micrometers.
There was a scientific desire to see the fine details of the interior structures of organic cells (nucleus, mitochondria...etc.). This required 10,000x plus magnification which was just not possible using Light Microscopes.
The Transmission Electron Microscope (TEM) was the first type of Electron Microscope to be developed.
It was developed by Max Knoll and Ernst Ruska in Germany in 1931.
- The first Scanning Electron Microscope (SEM) debuted in 1942 with the first commercial instruments around 1965.

How do Electron Microscopes Work?

The basic steps involved in all EMs:

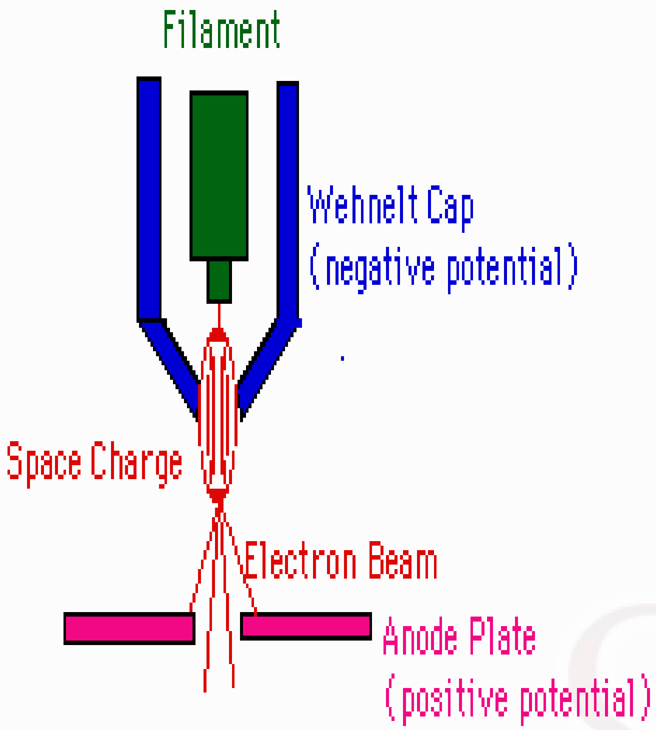
1. A stream of electrons is formed (by the Electron Source) and accelerated toward the specimen using a positive electrical potential
2. This stream is confined and focused using metal apertures and magnetic lenses into a thin, focused, monochromatic beam.
3. This beam is focused onto the sample using a magnetic lens.
4. Interactions occur inside the irradiated sample, affecting the electron beam. These interactions and effects are detected and transformed into an image.

# Components of Electron Microscope



# Components of Electron Microscope

**Electron Source (GUN)**




A Thermionic Electron Gun functions in the following manner:

1. An positive electrical potential is applied to the anode
2. The filament (cathode) is heated until a stream of electrons is produced
3. The electrons are then accelerated by the positive potential down the column
4. A negative electrical potential (~500 V) is applied to the Whenelt Cap
5. As the electrons move toward the anode any one emitted from the filament's side are repelled by the Whenelt Cap toward the optic axis (horizontal center)
6. A collection of electrons occurs in the space between the filament tip and Whenelt Cap. This collection is called a space charge
7. Those electrons at the bottom of the space charge (nearest to the anode) can exit the gun area through the small (<1 mm) hole in the Whenelt Cap
8. These electrons then move down the column to be later used in imaging

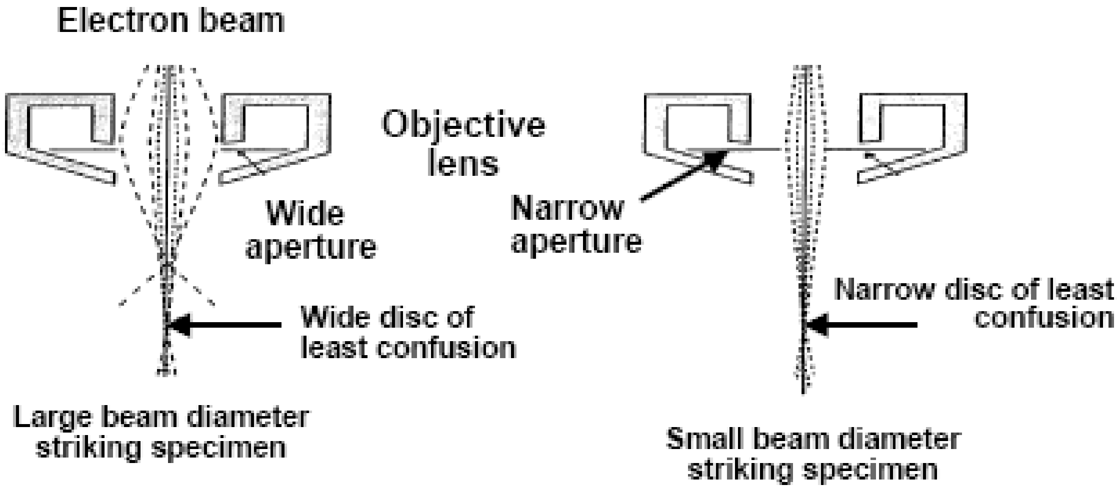
# Components of Electron Microscope

## Electromagnetic Lenses

### The Objective Lens - Aperture

- Since the electrons coming from the electron gun have spread in kinetic energies and directions of movement, they may not be focused to the same plane to form a sharp spot.

- By inserting an aperture, the stray electrons are blocked and the remaining narrow beam will come to a narrow “Disc of Least Confusion”

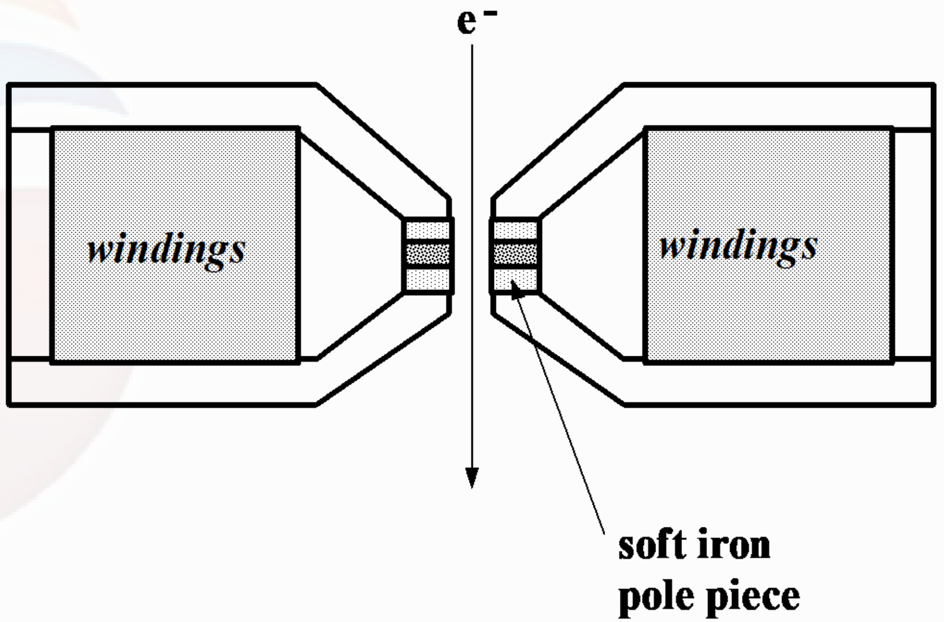


# The electromagnetic lens

- works at *fixed focal distance &* *variable focal length*

  - like the human eye lens, but *unlike* light optics

- simple rheostat can vary power of lens (varies current)




*electrons are charged, and are therefore deflected when they cross a magnetic field*

# Scanning Electron Microscope (SEM)

SEMs yield the following information:

**Topography:** The surface features of an object or "how it looks", its texture; detectable features limited to a few manometers

**Morphology:** The shape, size and arrangement of the particles making up the object that are lying on the surface of the sample or have been exposed by grinding or chemical etching; detectable features limited to a few manometers

**Composition:** The elements and compounds the sample is composed of and their relative ratios, in areas ~ 1 micrometer in diameter

**Crystallographic Information:** The arrangement of atoms in the specimen and their degree of order; only useful on single-crystal particles >20 micrometers

# Scanning Electron Microscope (SEM)

Scanning electron microscopy is used for inspecting topographies of specimens at very high magnifications using a piece of equipment called the scanning electron microscope. SEM magnifications can go to more than 300,000 X but most semiconductor manufacturing applications require magnifications of less than 3,000 X only. SEM inspection is often used in the analysis of die/package cracks and fracture surfaces, bond failures, and physical defects on the die or package surface.

**Principle of SEM:**

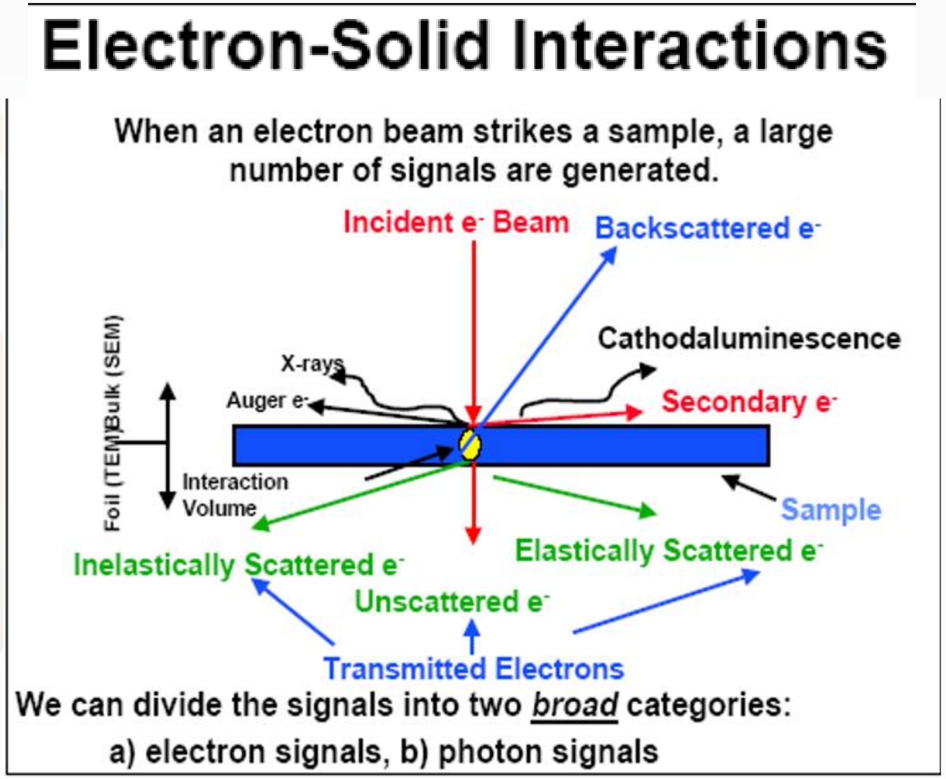
*During SEM inspection, a beam of electrons is focused on a spot volume of the specimen, resulting in the transfer of energy to the spot. These bombarding electrons, also referred to as primary electrons, dislodge electrons from the specimen itself. The dislodged electrons, also known as secondary electrons, are attracted and collected by a positively biased grid or detector, and then translated into a signal.*

*To produce the SEM image, the electron beam is swept across the area being inspected, producing many such signals. These signals are then amplified, analyzed, and translated into images of the topography being inspected. Finally, the image is shown on a CRT.*

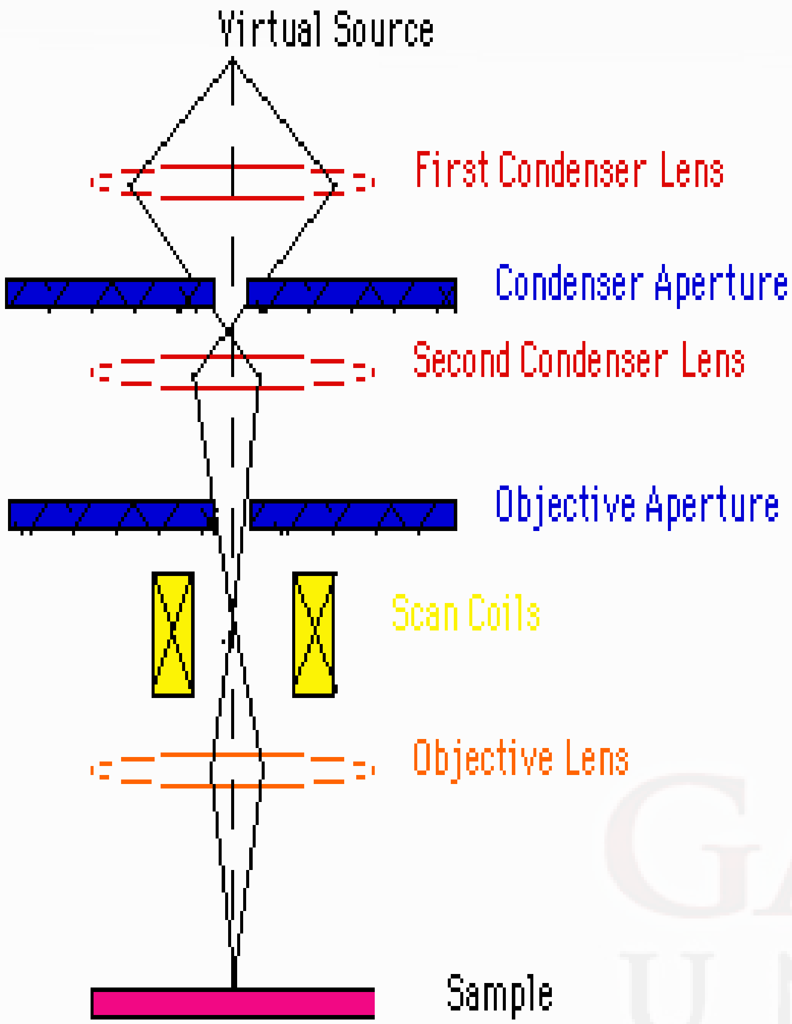
# Scanning Electron Microscope (SEM)

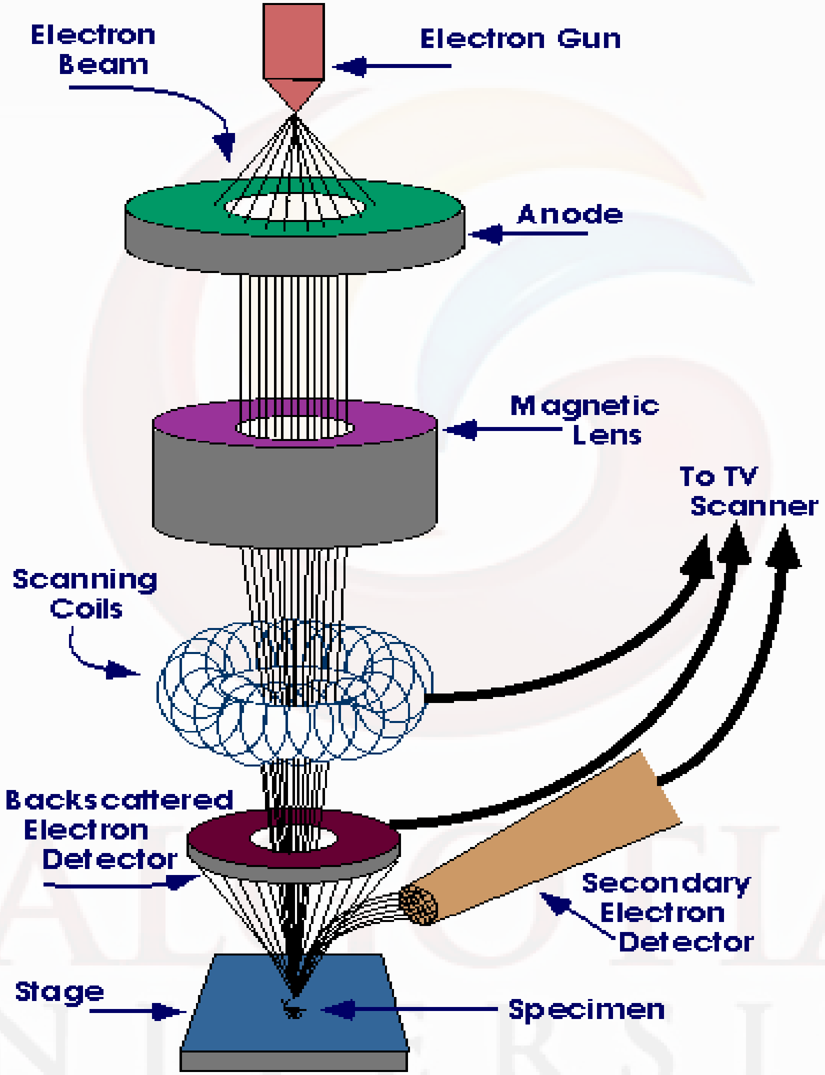
The energy of the primary electrons determines the quantity of secondary electrons collected during inspection. The emission of secondary electrons from the specimen increases as the energy of the primary electron beam increases, until a certain limit is reached. Beyond this limit, the collected secondary electrons diminish as the energy of the primary beam is increased, because the primary beam is already activating electrons deep below the surface of the specimen. Electrons coming from such depths usually recombine before reaching the surface for emission.

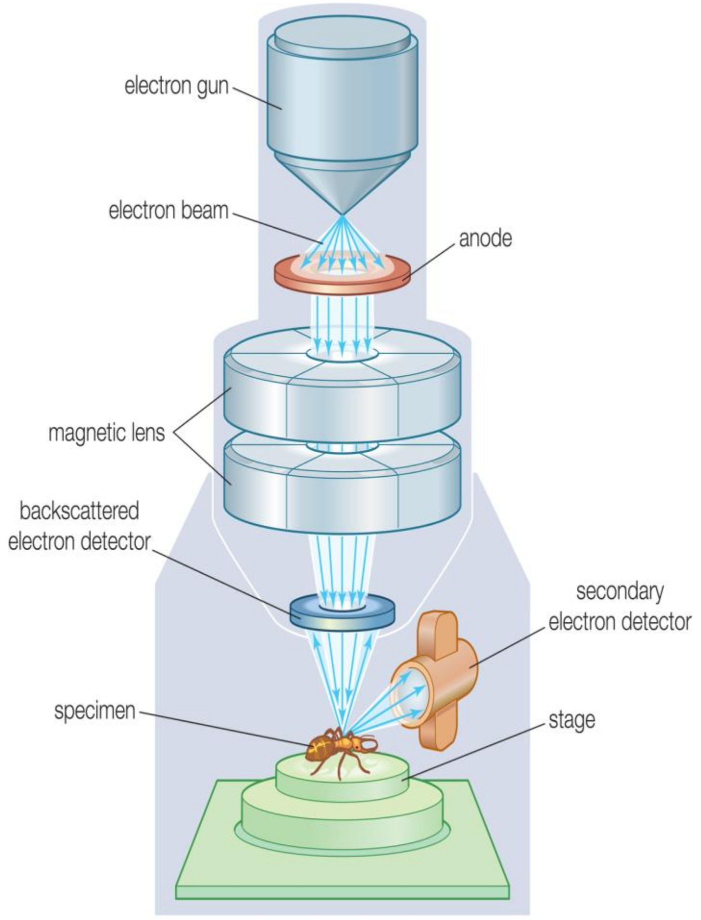
Aside from secondary electrons, the primary electron beam results in the emission of backscattered (or reflected) electrons from the specimen. Backscattered electrons possess more energy than secondary electrons, and have a definite direction. As such, they can not be collected by a secondary electron detector, unless the detector is directly in their path of travel. All emissions above 50 eV are considered to be backscattered electrons.



# Parts of Scanning Electron Microscope (SEM)

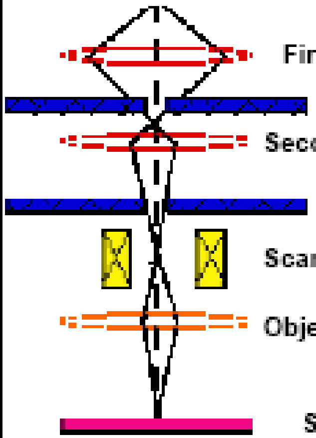


# Working of Scanning Electron Microscope (SEM)

## Scanning Electron Microscope

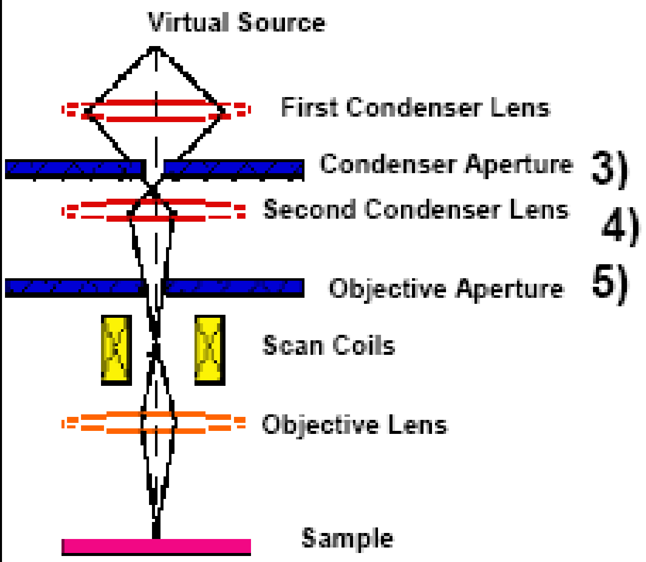



1) The "Virtual Source" at the top represents the electron gun, producing a stream of monochromatic electrons.

2) The stream is condensed by the first condenser lens (usually controlled by the "coarse probe current knob"). This lens is used to both form the beam and limit the amount of current in the beam. It works in conjunction with the condenser aperture to eliminate the high-angle electrons from the beam.

# Working of Scanning Electron Microscope (SEM)

## Scanning Electron Microscope




3) The beam is then constricted by the condenser aperture (usually not user selectable), eliminating some high-angle electrons.

4) The second condenser lens forms the electrons into a thin, tight, coherent beam and is usually controlled by the "fine probe current knob".

5) A user selectable objective aperture further eliminates high-angle electrons from the beam.

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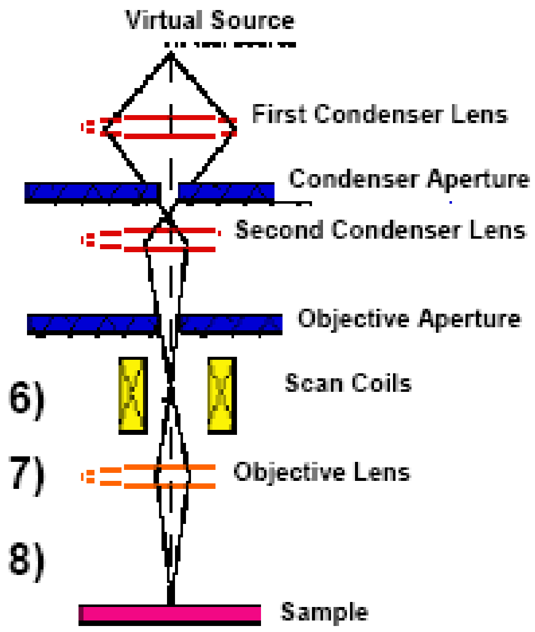
# Working of Scanning Electron Microscope (SEM)

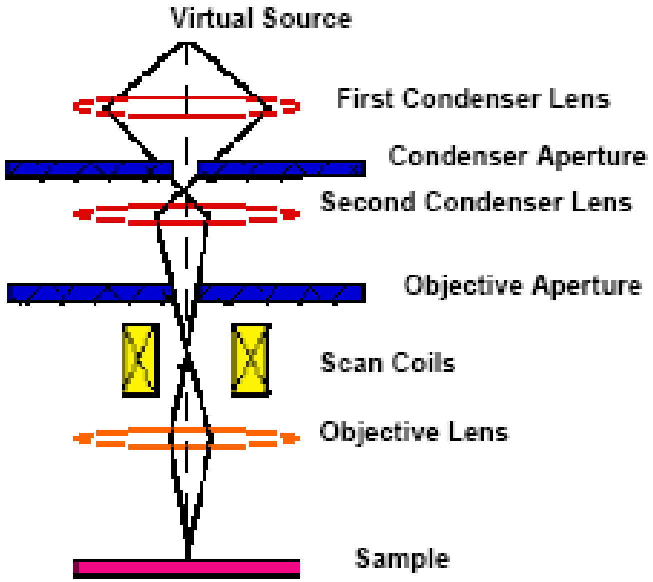
## Scanning Electron Microscope




6) A set of coils then "scan" or "sweep" the beam in a grid fashion (like a television), dwelling on points for a period of time determined by the scan speed (usually in the microsecond range).
7) The final lens, the objective, focuses the scanning beam onto the part of the specimen desired.
8) When the beam strikes the sample (and dwells for a few microseconds) interactions occur inside the sample and are detected with various instruments.

# Working of Scanning Electron Microscope (SEM)

## Scanning Electron Microscope




9) Before the beam moves to its next dwell point these instruments count the number of $e^-$ interactions and display a pixel on a CRT whose intensity is determined by this number (the more reactions the brighter the pixel).

10) This process is repeated until the grid scan is finished and then repeated, the entire pattern can be scanned 30 times/sec.

# Sample preparation  for SEM

Because the SEM utilizes vacuum conditions and uses electrons to form an image, special preparations must be done to the sample. All water must be removed from the samples because the water would vaporize in the vacuum. All metals are conductive and require no preparation before being used. All non-metals need to be made conductive by covering the sample with a thin layer of conductive material. This is done by using a device called a "**sputter coater**." The sputter coater uses an electric field and argon gas. The sample is placed in a small chamber that is at a vacuum. Argon gas and an electric field cause an electron to be removed from the argon, making the atoms positively charged. The argon ions then become attracted to a negatively charged gold foil. The argon ions knock gold atoms from the surface of the gold foil. These gold atoms fall and settle onto the surface of the sample producing a thin gold coating.

# Questions

Explain the basic principle of SEM
What is magnetic lens?
Explain the working of SEM
What are the applications of SEM?
What are the basic components used to design the SEM?

# References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